Chandra Contaminant Migration Model

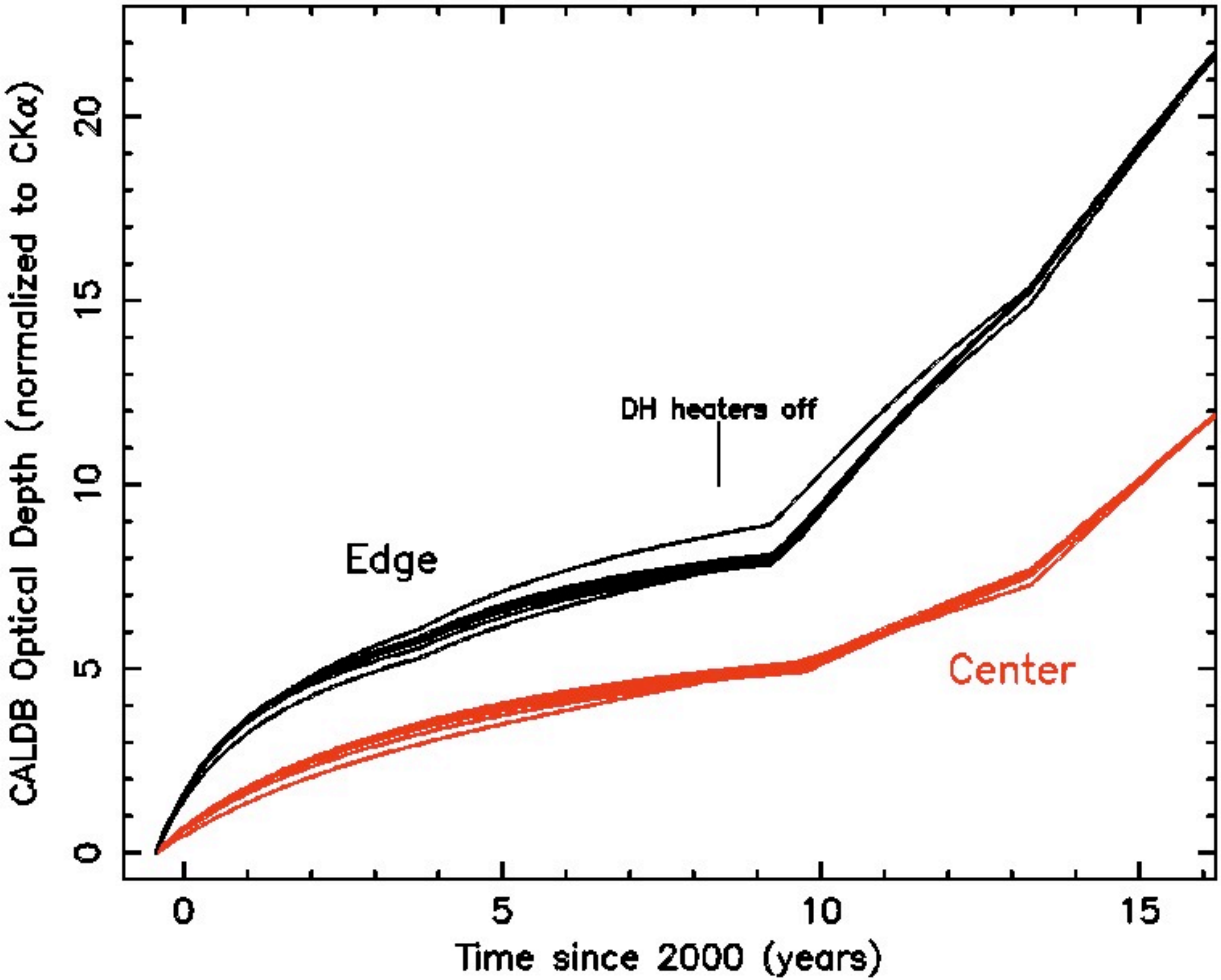
Doug Swartz & Steve O'Dell

Motivation:

The accelerated accumulation observed since ~2012 cannot be reproduced under the old assumptions of one (or more) gradually depleting contaminant source(s) -- any new paradigm must consider source(s) with rates *increasing* with time (but consistent within S/C trends).

Methods: *(the usual)*

(1) Simulate migration (vaporization/deposition) of potential contaminant(s) by solving a set of 1st order ODEs through explicit (forward) difference scheme and within thermal & geometric model constraints.
(2) Compare time evolution of material mass column density to observations at select locations on OBF filters to identify best candidate contaminant properties.



CALDB Optical Depth (normalized to CKα)
0
5
10
15
20
Time since 2000 (years)
DH heaters off
Edge
Center

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Simulation Constraints:

◆ Spacecraft geometry (surface areas & view factors) and time-averaged surface temperatures as determined by Neil Tice (LM) using flight data inputs to Thermal Desktop™ RADCAD (geometric) & SINDA FLUINT (radiative/conductive thermal) modules; accounts for effects of DH heaters being turned off ~2008.4 (t~9 yr)

◆ X-ray observations of contamination effects throughout the mission as documented in CALDB contamination model N0009 (June 2014); constrains time evolution and spatial distribution of contaminant optical depth, τ(t,x,y), proportional to the mass surface density, μ (t,x,y)

◆ Temperature dependence of vaporization rate follows Clausius-Clapeyron relation $\rho(T) = \rho(T_0)\ (T/T_0)^{1/2} exp(-\Delta H(1/T-1/T_0)/R)$

where $\rho(T)$ is the mass vaporization rate at temperature T, ΔH is the vaporization enthalpy, and R the universal gas constant

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Simulation Parameters:

◆ Material (enthalpy, ΔH, and reference temperature, T_0, fixed); vaporization rate normalization $\rho(T_0)$ is a free parameter

◆ <u>Declining source rate</u>: $S(t)=A(1+B*\exp(-t/C))$ where A, B & C are chosen to follow the early build-up ($t<2008$) at the center of S3

◆ <u>Rising source rate</u>: $S'(t) \propto A'\exp(-B'(1/T-1/T_0)$ where the normalization, A′ is a free parameter and B′ is given by the enthalpy ΔH of the supposed contaminant. Physically, A′ includes a multiplicative scale factor representing the outgassing 'escape efficiency'.

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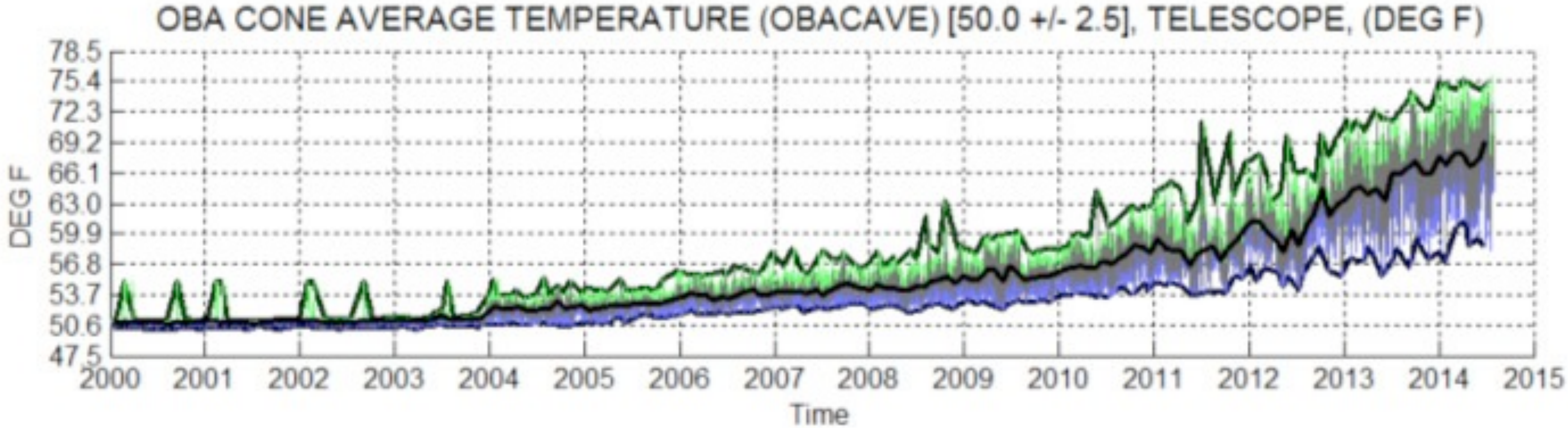
$$T_{\mathrm{OBA}}(t) = T_0 \left[\, 1+0.006\, exp((t-8.1)/4.0) \,\right]$$



$$S'(t) = S'(T_0)\, (T_{\mathrm{OBA}}(t)/T_0)^{1/2} * exp[-\Delta H/RT_0(T_0 - T_{\mathrm{OBA}}(t))/T_{\mathrm{OBA}}(t)]$$

...the Clausius-Clapeyron equation for a time-dependent T_{OBA}

(ΔH and T_0 are those of the contaminating material)

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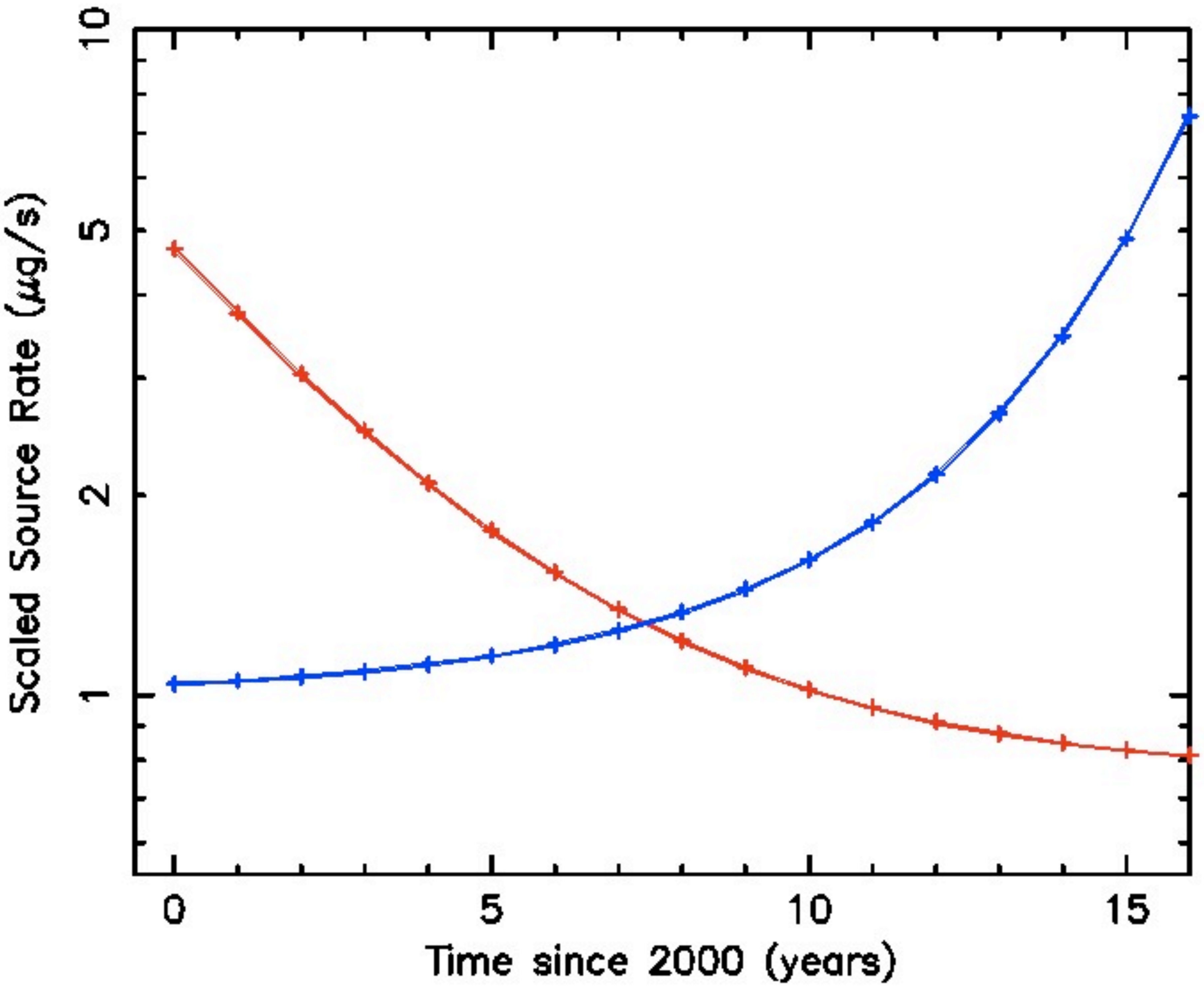

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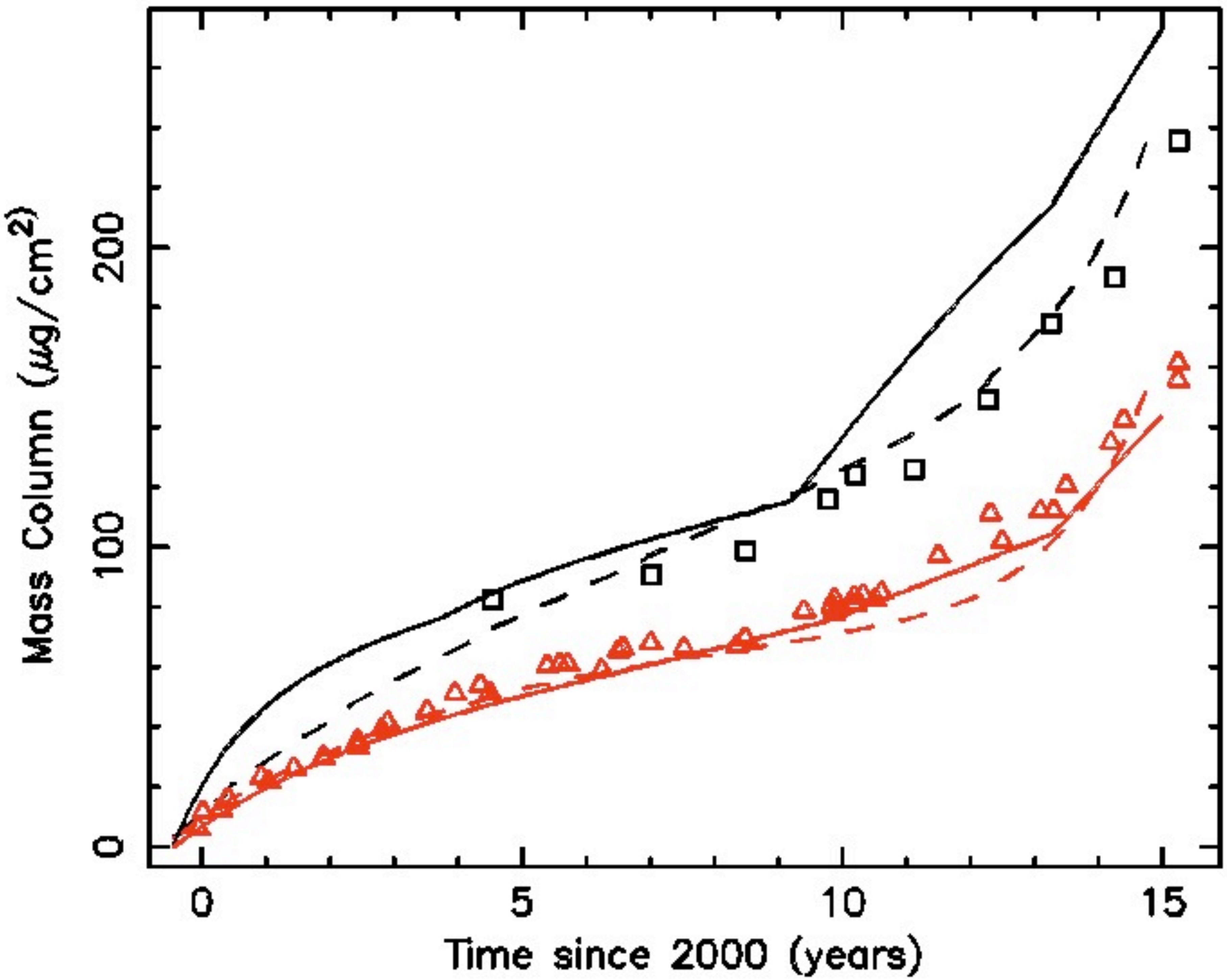

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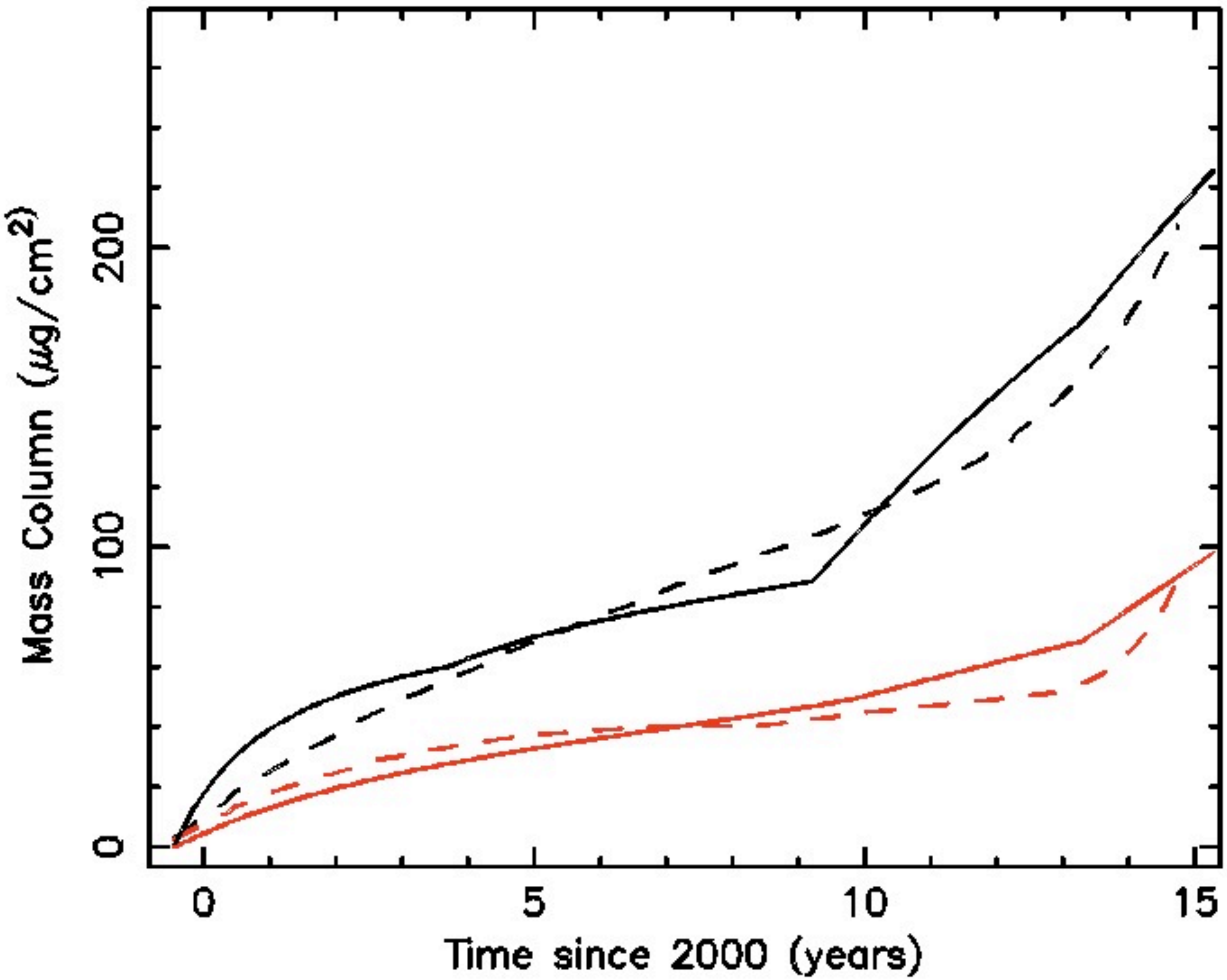

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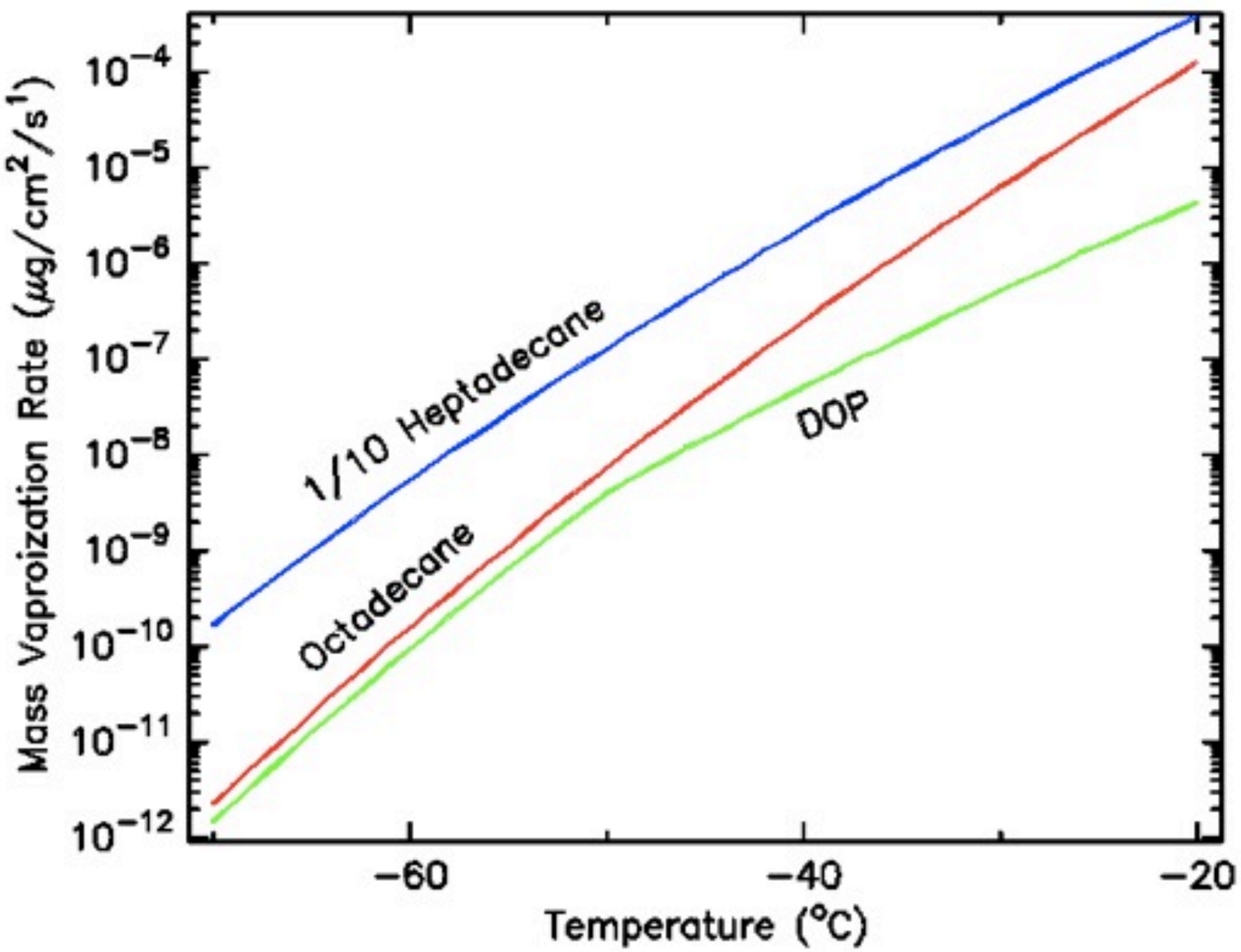

T °C	Octadecane	0.1*Hepta-decane
-60	1.6×10^{-10}	5.6×10^{-9}
-40	2.5×10^{-7}	2.4×10^{-6}
+10	0.27	0.21
+20	2.4	1.3

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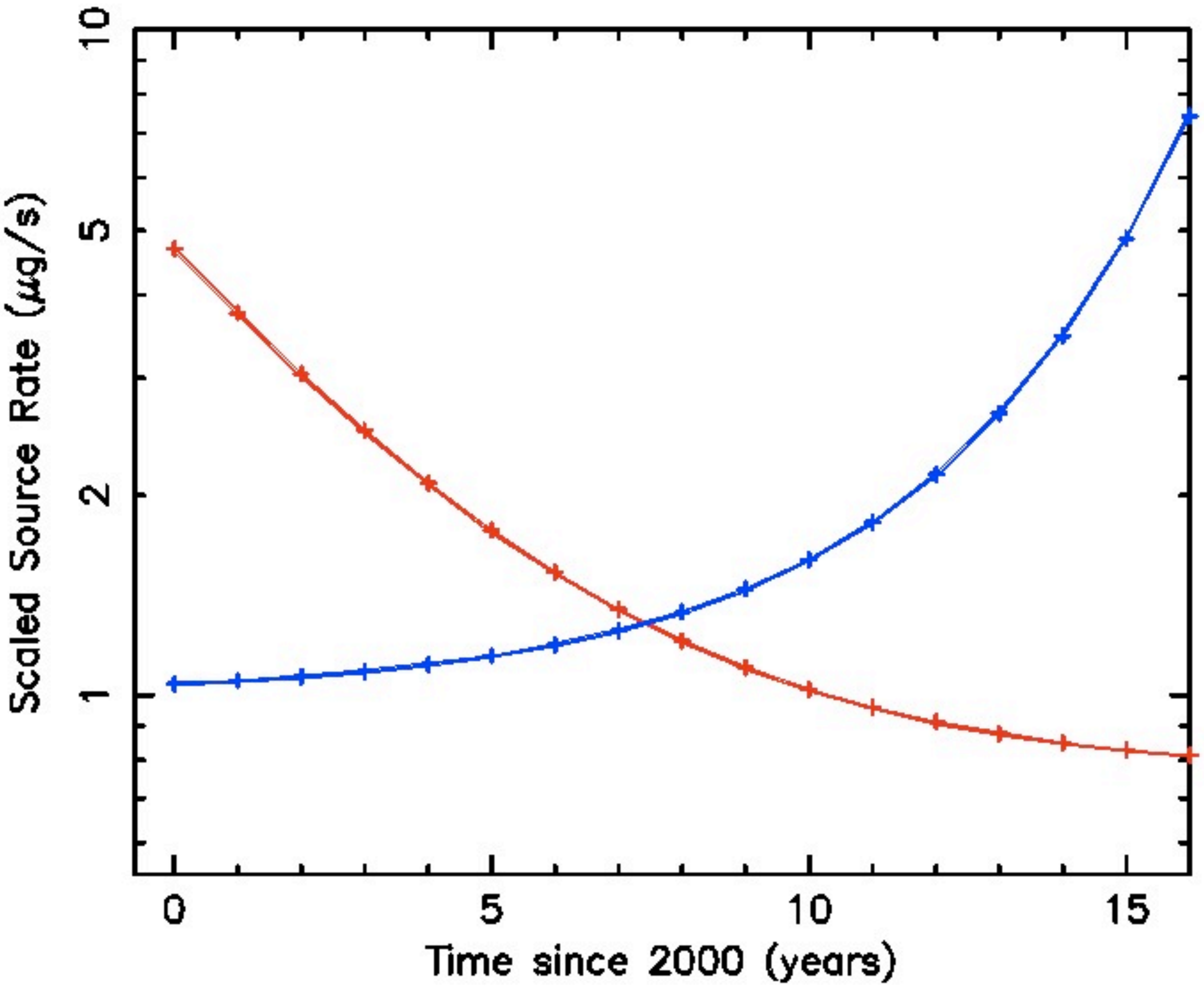

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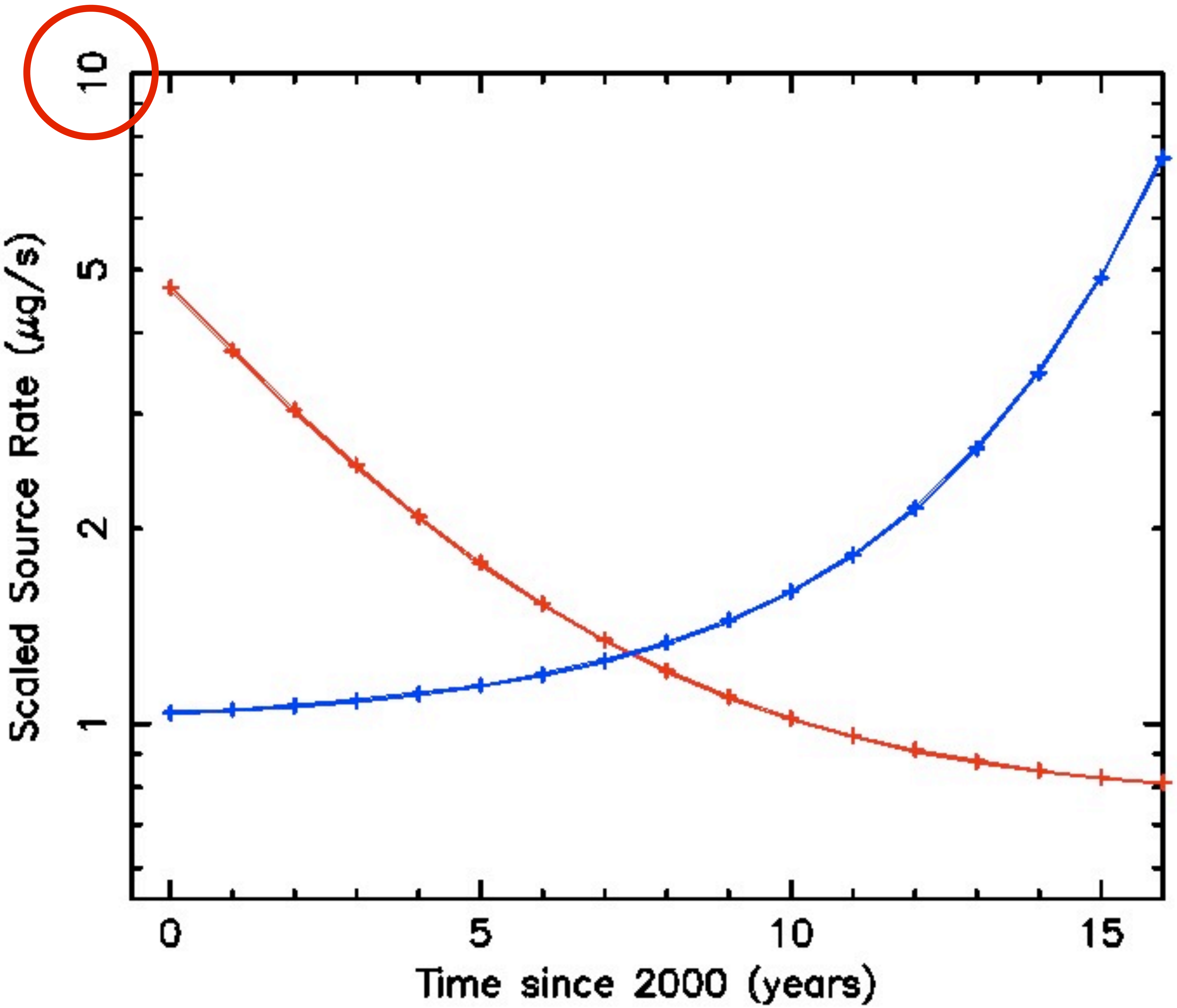

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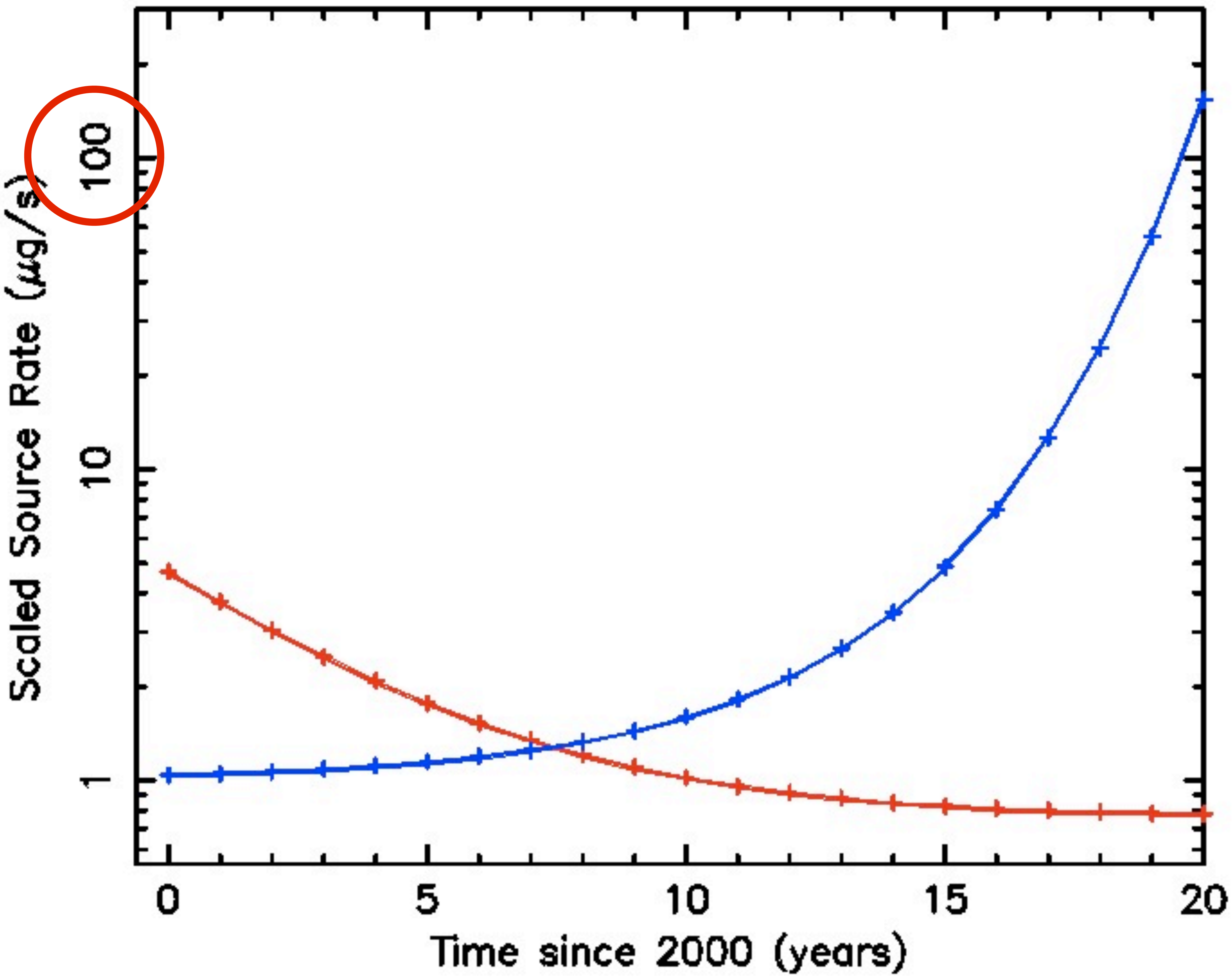


Chandra Contaminant Migration Model
SUMMARY

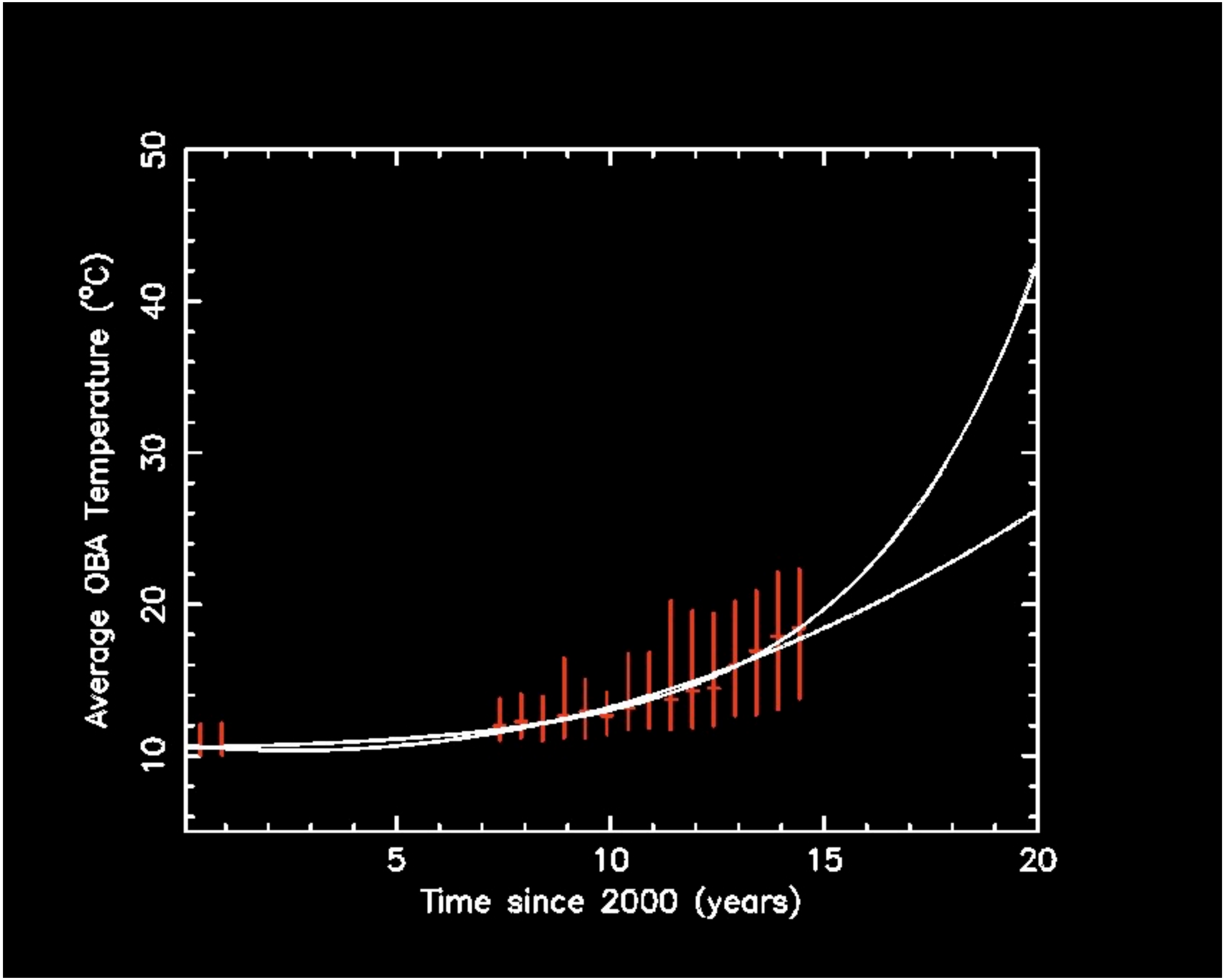
◆ Volatility of contaminants can be tightly constrained by simulations.

◆ Accelerated buildup since 2010 has 30* higher volatility at -60^{o}C ; likely to 'clean' readily at elevated temperatures.

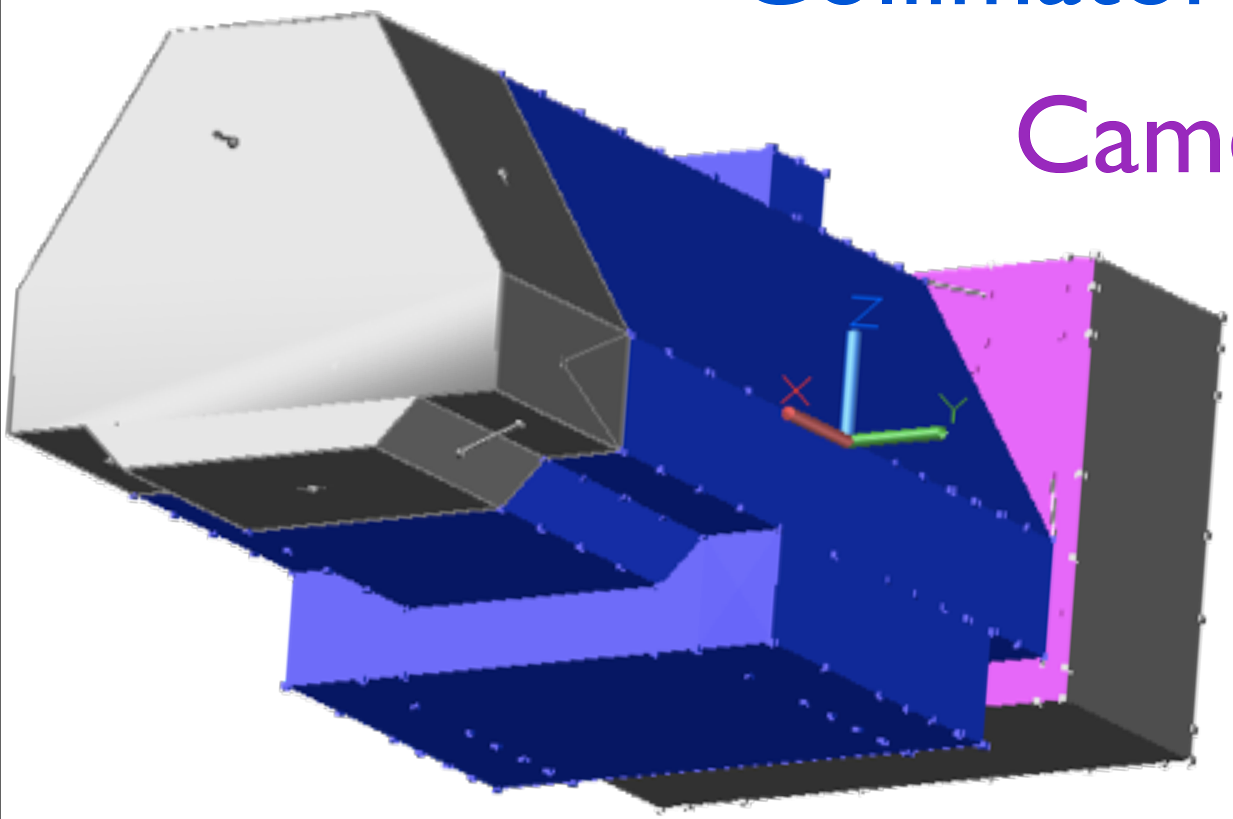
◆ Current exponentially increasing trend in OBA temperature is predicted to lead to extremely rapid buildup of 'second' contaminant (5$*$source rate for 10^{o}C increase in 3 yrs; 30$*$ in 5 yr; but polynomial fit implies only 3$*$ in 5 yr).

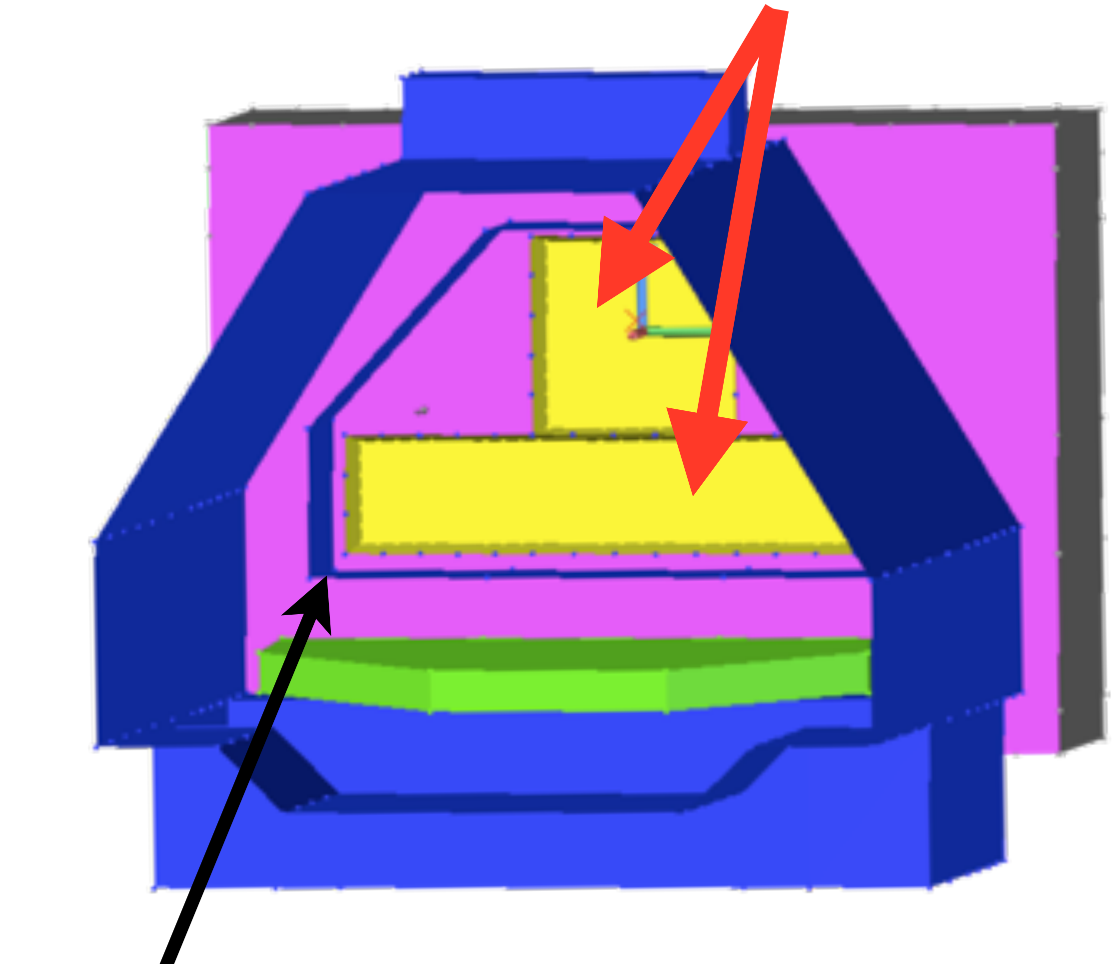
◆ At t~16 yrs, 0.4 grams of contaminant is within the S/C with only 5% (20mg) on OBFs (~270 μg/cm^2).

backup slides


Average OBA Temperature (°C)
10
20
30
40
50
5
10
15
20
Time since 2000 (years)

Geometry Model

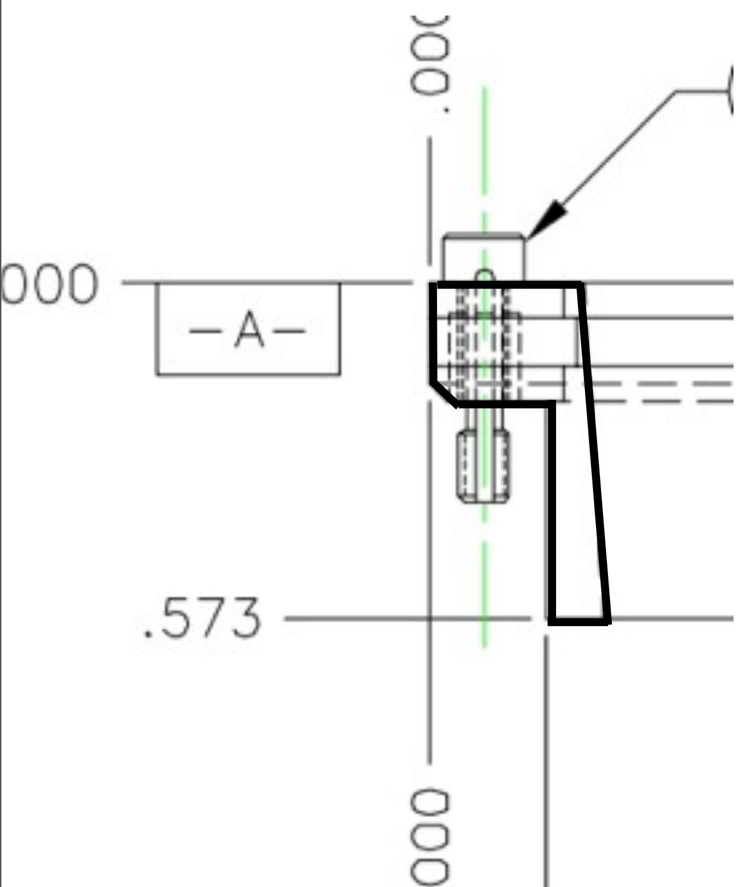


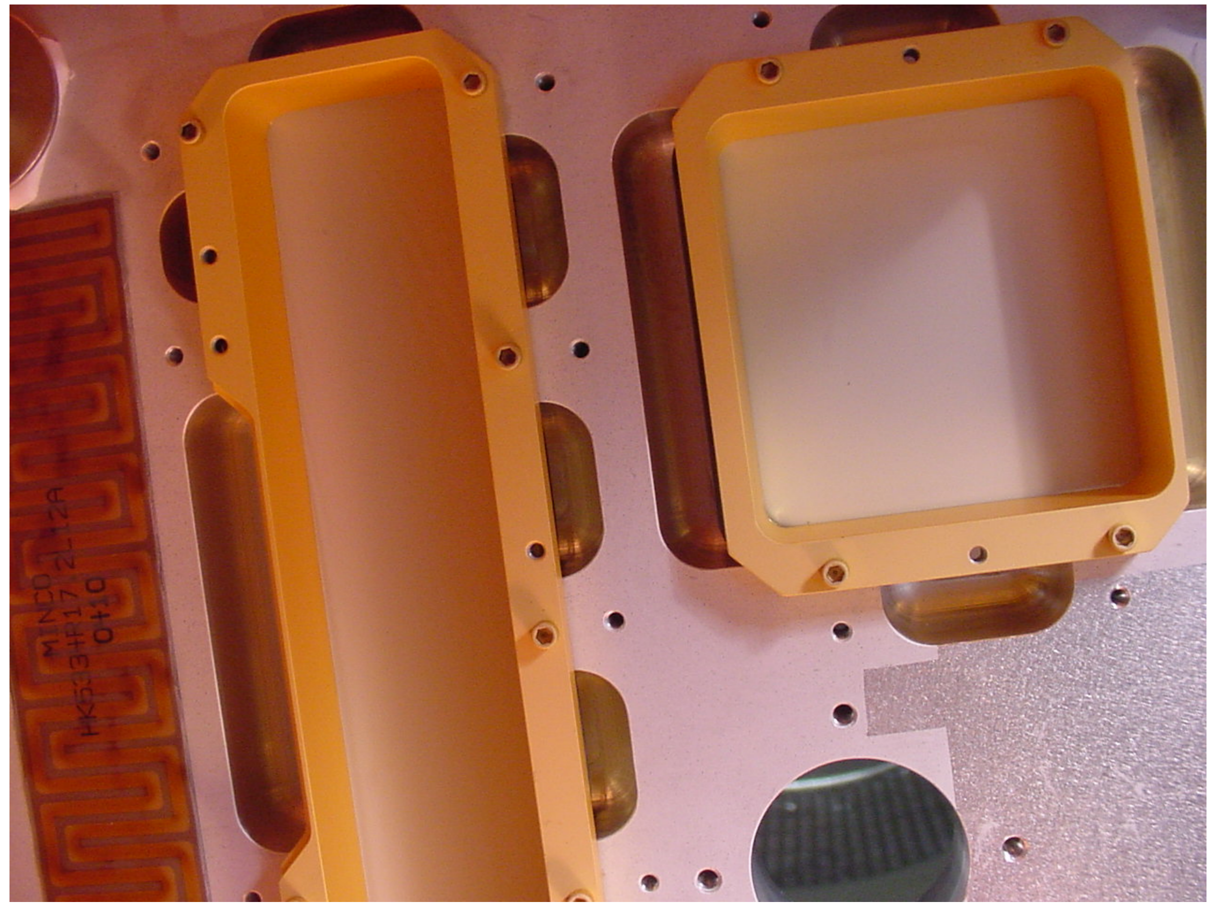


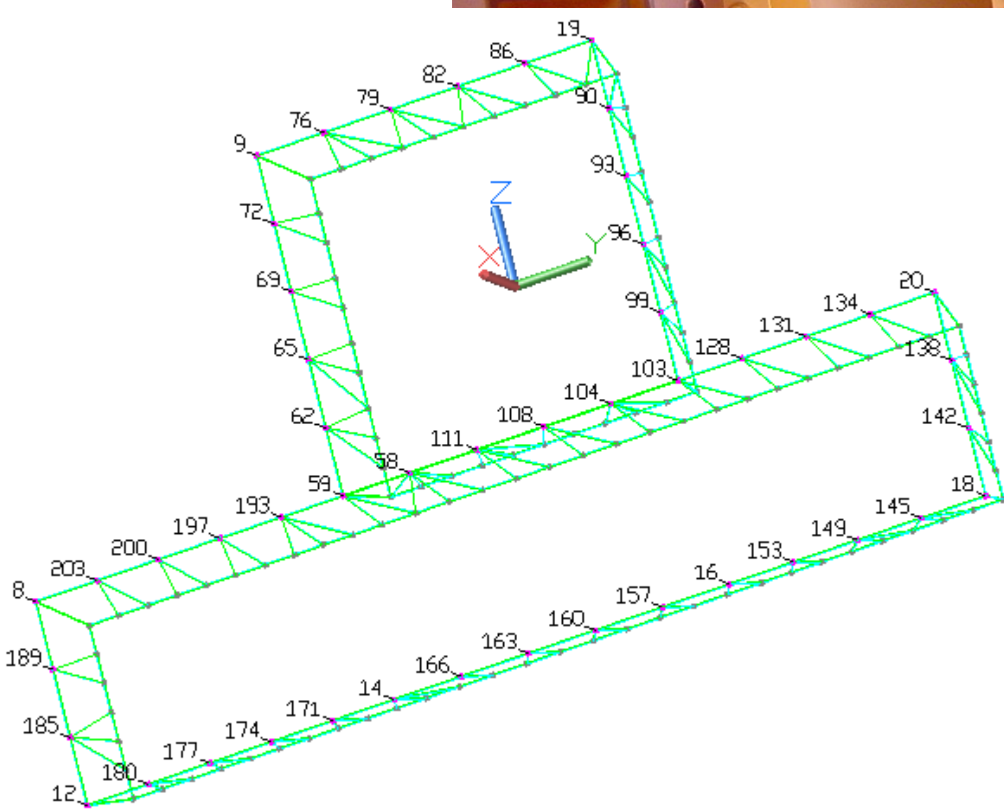
From Neil Tice/LMC

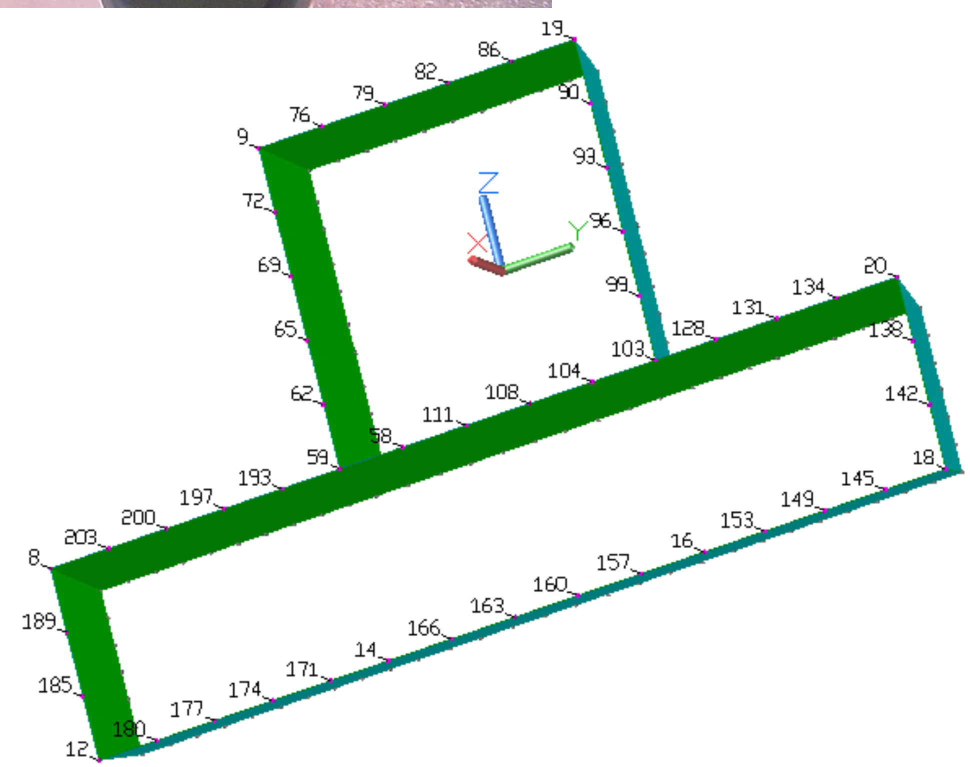
Thermal Desktop (finite element):
RADCAD
  to calculate geometric view factors
SINDA FLUINT
  to calculate temperatures
738 nodes, 121 OBF-I, 203 OBF-S
  186x186p/node (I), 146x212p/node (S)

Geometry Model



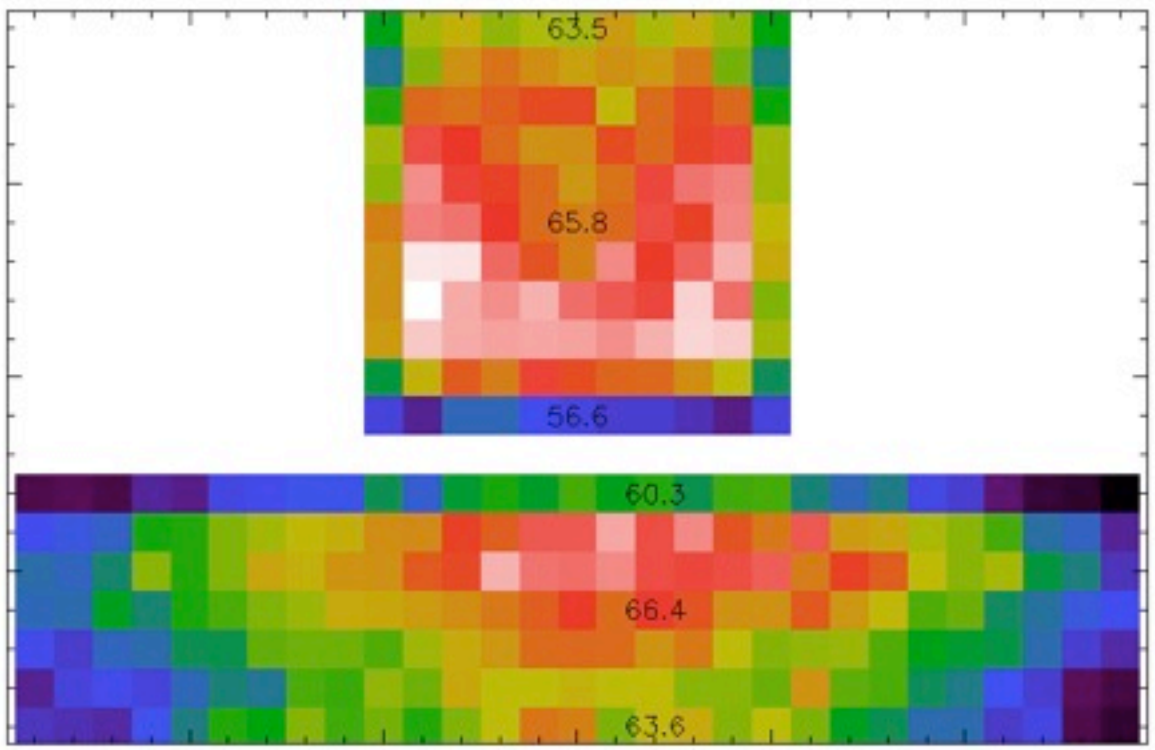






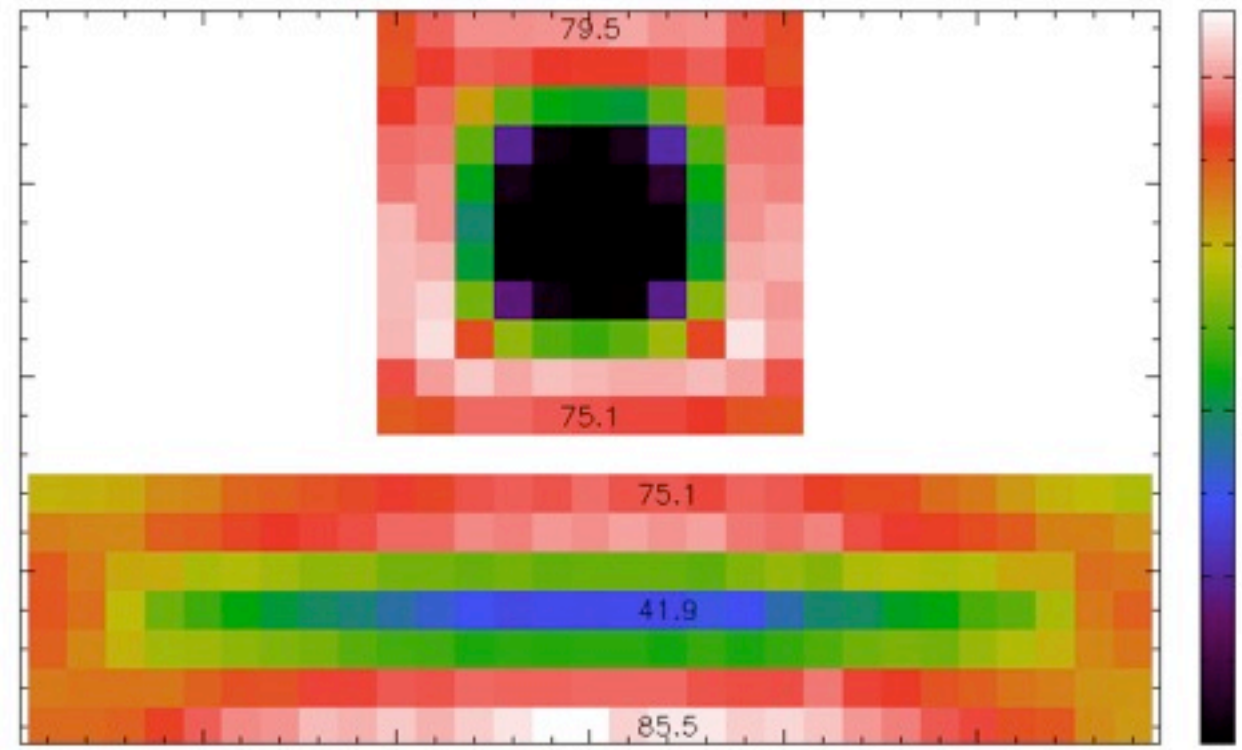
Chandra Contaminant Migration Model Results

Mass Column of Octadecane ($C_{18}H_{38}$) at t=9 years



low volatility (0.10)

“deposition” dominated: central regions have highest accumulation because center views more nearby cold surfaces, pattern is asymmetric



high volatility (2.50)

“thermal” (vaporization) dominated: warm central regions begin to clean, pattern follows local temperature distribution with more material near cold edges